

Performer Selection in Human Reliability Analysis: D numbers Approach

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Abstract: Dependence assessment among human errors in human reliability analysis (HRA) is an significant issue. Many previous works discussed the factors influencing the dependence level but failed to discuss how these factors like "similarity of performers" determine the final result. In this paper, the influence of performers on HRA is focused, in addition, a new way of D numbers which is usually used to handle with the multiple criteria decision making (MCDM) problems is introduced as well to determine the optimal performer. Experimental result demonstrates the validity of proposed methods in choosing the best performers with lowest the conditional human error probability (CHEP) under the same circumstance.

Keywords: Human reliability analysis (HRA), D numbers, D-S evidence theory, multiple criteria decision making (MCDM), nuclear power plant.

1 Introduction

Human error is an important factor to be considered in the design and risk assessment of large complex systems [71], such as nuclear power plant operation [1, 28, 66], air traffic control [27, 44], grounding of oil tankers [37] and IIR filters [40]. Dependence analysis within human reliability analysis (HRA) refers to evaluating the influence of the failure of the operator to perform one task on the failure probabilities of subsequent tasks [51]. Dependence between two sequent tasks within human reliability analysis means if the preceding task fails, the failure probability of the following task is higher than the success [72]. Therefore, an appropriate assessment of dependence is crucial to avoid underestimation of the risk. In the existing methods, the result of dependence assessment is a Conditional Human Error Probability (CHEP), given failure on the preceding task [5, 72].

The most widely used method is the technique for human error rate prediction (THERP) dependence method [26, 50]. THERP introduces five levels of dependence corresponding to different values of CHEPs and it suggests some of the factors that may influence the dependence level. The THERP model refers to three main factors: "Closeness in Time" (CT), "Task Relatedness" (TR) and "Similarity of Performers" (SP). And the assessment requires considerable expert judgment on identifying which factor is important and on how these factors influence the dependence level. As a result, a highly subjective process that may be insufficient traceability and reproducibility would be inevitable.

To overcome this limitation, Decision Trees (DTs) method [2, 17] and Fuzzy Expert System (FES) [38, 39, 72] have been introduced to extend the THERP dependence model. However, the influence of performer is partially ignored to some degree in the existing methods, which is critical factor determining the dependence level. In addition, it is inevitable to deal with uncertainty in the modeling the influence of performer. As a result, it is necessary to develop a new HRA

math model. The purpose of this paper is to present a model and discuss how the differences of performers affect the final result as well as conditional human error probability (CHEP). The proposed method is based on D numbers [10] which is efficient to handle uncertainty multiple criteria decision making problem (MCDM) [9, 55, 56].

The paper is organized as follows. In Section 2, some preliminaries are briefly introduced, including HRA, D-S evidence theory and D numbers. In Section 3, the proposed methodology in HRA is detailed. In Section 4, an application of the proposed HRA method in post initiator HFEs of a nuclear power plant is used to illustrate the effectiveness of the presented method. Conclusion is given in Section 5.

2 Preliminaries

In this section, some preliminaries including human reliability analysis (HRA), evidence theory and D numbers, are briefly introduced.

Definition 1. Assume that task T_B is subsequent to task T_A , and B and A are the corresponding failure events. P_A and P_B are basic probability of failure of task T_A and T_B , respectively, then the conditional human error probability (CHEP) of B given is defined as follows: [47]

$$P_{XD}(B|A) = (1 + K \times P_B)/(K + 1) \quad (1)$$

where $K=0, 1, 6, 9, \infty$, for dependence levels CD, HD, MD, LD and ZD, where XD=CD, HD, MD, LD and ZD, respectively. It reflects the less dependent the two tasks are, the lower the failure of probability is.

2.1 D-S evidence theory

It's necessary to deal with uncertainty [34, 35, 63, 65] and many math models are presented such as fuzzy set [12, 41, 53, 64], Z-numbers [24, 25, 59], belief function [20, 60, 61] and bio-inspired model [62]. Due to its efficiency to model uncertainty, evidence theory is widely used in decision making [3, 14], pattern recognition [4, 6, 19] evidential reasoning [29, 67–69] and information fusion [46, 58]. Some basic definitions of D-S theory are briefly introduced [7, 42]:

Definition 2. A set of hypotheses Θ is the exhaustive hypotheses of variable and the elements are mutually exclusive in Θ . Then Θ is called the frame of discernment, defined as follows [7, 42]:

$$\Theta = \{H_1, H_2, \dots, H_i, \dots, H_N\} \quad (2)$$

The power set of Θ is denoted by 2^Θ , and

$$2^\Theta = \{\emptyset, \{H_1\}, \dots, \{H_N\}, \{H_1, H_2\}, \dots, \{H_1, H_2, \dots, H_i\}, \dots, \Theta\} \quad (3)$$

where \emptyset is an empty set.

Definition 3. A BPA function m is a mapping of 2^Θ to a probability interval $[0, 1]$, formally defined by [7, 42]:

$$m : 2^\Theta \rightarrow [0, 1] \quad (4)$$

which satisfies the following conditions:

$$m(\emptyset) = 0 \quad \sum_{A \in 2^\Theta} m(A) = 1 \quad 0 \leq m(A) \leq 1 \quad A \in 2^\Theta \quad (5)$$

The mass $m(A)$ represents how strongly the evidence supports A with the efficiency to model uncertainty [9]. Conflicting management with Dempster rule is still an open issue [52]. In addition, many operations on mass function have been proposed such correlation [21], distance [11], entropy measure [31, 36], divergence measure [13, 45] and negation [15, 16].

For the same evidence, the different BPAs come from the different evidence resources. The Dempster’s combination rule can be used to obtain the combined evidence [7]:

$$\begin{cases} m(\emptyset) = 0 \\ m(A) = \frac{\sum_{B \cap C = A} m_1(B)m_2(C)}{1-K} \end{cases} \tag{6}$$

where $K = \sum_{B \cap C = \emptyset} m_1(B)m_2(C)$. It should be mentioned that many methods are presented to deal with the open issues of evidence theory.

Definition 4. Let m be a BPA on Θ . Its associated pignistic probability function $Bet P_m: \Theta \rightarrow [0, 1]$ is defined as:

$$Betp_m(\omega) = \sum_{A \in \Theta, \omega \in A} \frac{1}{|A|} \frac{m_A}{1 - m(\emptyset)}, m(\emptyset) \neq 1, \tag{7}$$

where $|A|$ is the cardinality of subset A .

2.2 D numbers

The real application exists the uncertainty [22, 57]. To address the Multiple criteria decision making problem (MCDM) issue [23], a new mathematical tool called D numbers [10] to represent uncertain information is proposed. The D numbers overcome several limitations the D-S theory involved.

Definition 5. Let Ω be a finite nonempty set, a D number is a mapping that $D: \Omega \rightarrow [0,1]$, with

$$\sum_{A \in \Omega} D(A) \leq 1 \quad \text{and} \quad D(\emptyset) = 0. \tag{8}$$

where \emptyset is an empty set and A is a subset of Ω [10].

Besides the empty set is not necessary set ZERO [48, 49], it should be pointed out that different from D-S theory, the elements in set ω do not require mutually exclusive and the completeness constraint is not necessary in D numbers. If $\sum_{A \in \Omega} D(A) \leq 1$, the information is said to be complete; Otherwise, the information is assumed to be incomplete.

For a discrete set $\Omega = \{b_1, b_2, \dots, b_i, b_j, \dots, b_n\}$, where $b_i \in \mathbb{R}$ and $b_i \neq b_j$, when $i \neq j$, a special form of D numbers can be expressed by

$$\begin{aligned} D(b_1) &= v_1 \\ D(b_2) &= v_2 \\ &\dots \\ D(b_i) &= v_i \\ D(b_j) &= v_j \\ &\dots \\ D(b_n) &= v_n \end{aligned} \tag{9}$$

simply denoted as $D = \{(b_1, v_1), (b_2, v_2), \dots, (b_i, v_i), (b_j, v_j), \dots, (b_n, v_n)\}$, where $v_i > 0$ and $\sum_{i=1}^n v_i \leq 1$

1. If $\sum_{i=1}^n v_i = 1$, the information is said to be complete; If $\sum_{i=1}^n v_i < 1$, the information is said to be incomplete. It is effective and convenient that using the form of D numbers to express the uncertain information in the real world.

Definition 6. Let $D_1 = \{(b_1^1, v_1^1), \dots, (b_i^1, v_i^1), \dots, (b_n^1, v_n^1)\}$, $D_2 = \{(b_1^2, v_1^2), \dots, (b_j^2, v_j^2), \dots, (b_m^2, v_m^2)\}$ be two D numbers, the combination of D_1 and D_2 , indicated by $D = D_1 \oplus D_2$, is defined by

$$D(b) = v \tag{10}$$

with

$$b = \frac{b_i^1 + b_j^2}{2} \tag{11}$$

$$v = \frac{v_i^1 + v_j^2}{2} / C \tag{12}$$

$$C = \begin{cases} \sum_{j=1}^m \sum_{i=1}^n (\frac{v_i^1 + v_j^2}{2}), & \sum_{i=1}^n v_i^1 = 1 \quad ; \quad \text{and} \quad \sum_{j=1}^m v_j^2 = 1; \\ \sum_{j=1}^m \sum_{i=1}^n (\frac{v_i^1 + v_j^2}{2}) + \sum_{j=1}^m (\frac{v_c^1 + v_j^2}{2}), & \sum_{i=1}^n v_i^1 < 1 \quad \text{and} \quad \sum_{j=1}^m v_j^2 = 1; \\ \sum_{j=1}^m \sum_{i=1}^n (\frac{v_i^1 + v_j^2}{2}) + \sum_{j=1}^m (\frac{v_i^1 + v_c^2}{2}), & \sum_{i=1}^n v_i^1 = 1 \quad \text{and} \quad \sum_{j=1}^m v_j^2 < 1; \\ \sum_{j=1}^m \sum_{i=1}^n (\frac{v_i^1 + v_j^2}{2}) + \sum_{j=1}^m (\frac{v_c^1 + v_j^2}{2}) \\ + \sum_{j=1}^m (\frac{v_i^1 + v_c^2}{2}) + \frac{v_c^1 + v_c^2}{2}, & \sum_{i=1}^n v_i^1 < 1 \quad \text{and} \quad \sum_{j=1}^m v_j^2 < 1; \end{cases} \tag{13}$$

where $v_c^1 = 1 - \sum_{i=1}^n v_i^1$ and $v_c^2 = 1 - \sum_{j=1}^m v_j^2$

In the meanwhile, an aggregation operator is proposed on this special D number, it is defined as below.

Definition 7. Let $D = \{(b_1, v_1), (b_2, v_2), \dots, (b_i, v_i), \dots, (b_n, v_n)\}$ be a D number, the integration representation of D number is defined as:

$$I(D) = \sum_{i=1}^n b_i v_i \tag{14}$$

3 The proposed method

The motivation behind the development of the proposed method is to select best performers which is the key factor in HRA among alternatives using D numbers proposed by Deng [10]. The influence of performers should be paid more attention. After figuring out the best performers

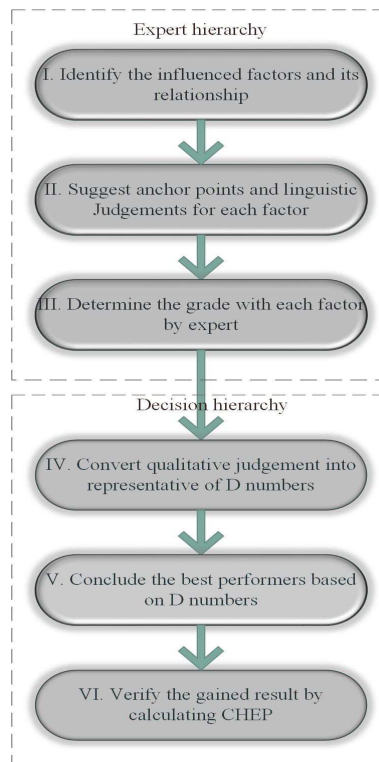


Figure 1: Framework of the proposed method

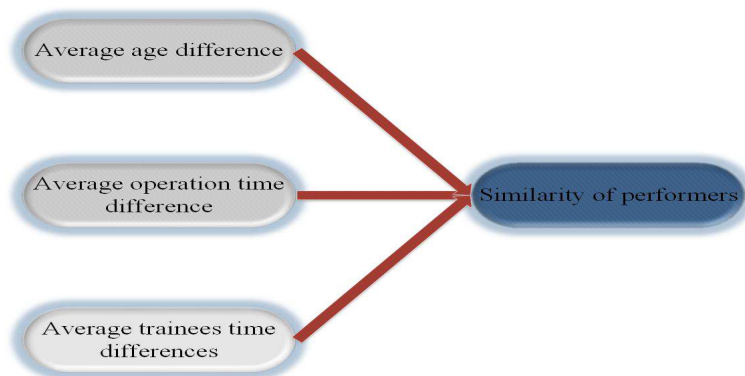


Figure 2: The factor affecting the performers

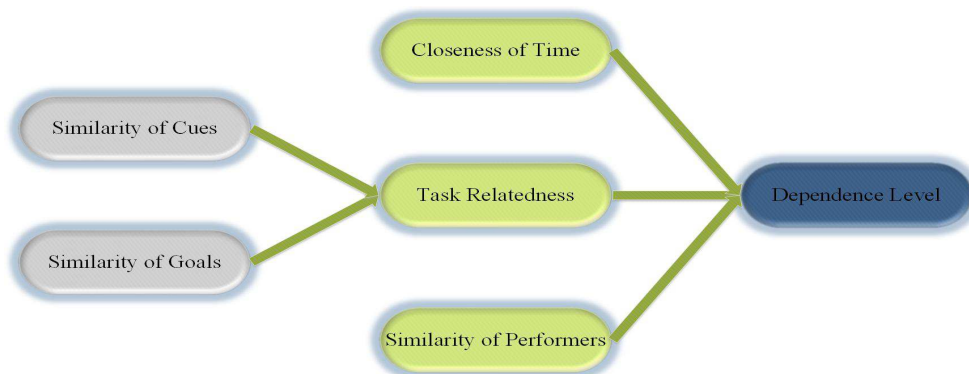


Figure 3: Functional relationships among the input factors of the dependence level

based on D numbers, the result through calculating the CHEP will be verified. The flow chart is shown in Fig. 1.

Step 1. Identify the influenced factors and the functional relationship among them: The first step is to determine the factors that may have influence on the dependence between two human failure events. For example, the THERP [72] model refer to five main factors: "closeness in time", "task relatedness", "similarity of performers", "similarity of cues" and "similarity of goals". And as for the performers, the influential factors the similarity of performers could be divided into three: "the average age among performers", "the average trainees time among performers" and "average operation time on the same task among performers". The relationship is shown in Fig. 2 and Fig. 3.

Step 2. Suggest anchor points and linguistic judgements for each factor: anchor points and linguistic judgements are provided by domain experts in advance as guidance for the HRA analyst's judgement of the input factors. Furthermore, due to the frequent ignorance of performers, the influential factors "the average age among performers", "the average trainees time among performers" and "average operation time on the same task among performers" are proposed. Their anchor points are shown in Tables (1-3). And a set of anchor points and linguistic judgements for the input factor SP is presented in Table 4, with the associated levels of dependence of performers. Dependence level of an input factors indicates the dependence level between two tasks with respect to this factor. For example, dependence level "ZD" in Table 4 means that the dependence level between two tasks is zero dependence with respect to the factor "similarity of performers".

"Average operation time difference" anchor points	Linguistic judgement	Dep. level
Less than 30 min	The tasks are accomplished by the same individual in operation time	CD
More than 30 min but less than 1h	High level of performer similarity in operation time exists	HD
More than 1h but less than 1.5h	The level of performer similarity in operation time is medium	MD
More than 1.5h but less than 2h	A low level of performers similarity in operation time exists	HD
More than 2h	NO similarity of performers in operation time is present between tasks	ZD

Table 1: Anchor points for input factor "average operation time difference"

"Average age difference" anchor points	Linguistic judgement	Dep. level
less than 1 year	The age of the two performers are basically the same	CD
more than 1 year but less than 3 years	The age similarity of two performers are almost the same	HD
more than 3 years but less than 5years	The age level of performers similarity is medium	MD
more than 5 years but less than 7years	The difference of the two performers are quite different in age	HD
more than 7 years	The tasks are accomplished by the completely different individuals	ZD

Table 2: Anchor points for input factor "average age difference"

"Average trainees time difference" anchor points	Linguistic judgement	Dep. level
less than 1 year	The operating technology between two performers is basically same	CD
more than 1 year but less than 1.5 year	The technology difference between two performers are slight	HD
more than 1.5 years but less than 2 years	The level of operating technology between two performers is medium	MD
more than 2 years but less than 2.5 years	The operating technology between two performers is basically different	HD
more than 2.5 years	The technology of the two teams are different	ZD

Table 3: Anchor points for input factor "average trainees time difference"

Step 3. Determine the grade with each factor by expert: It is supposed that the expert is totally authoritative. According to the collected data, the expert is asked to give their qualified judgement on each factor. The factor need to be judged by the expert are: the average age among performers, the average trainees time among performers, average operation time on the same task among performers, "closeness in time", "task relatedness". Due to our purpose is to verify best performers, the factors "closeness in time", "task relatedness" are set as constant.

Anchor points	Linguistic judgement	Dep. level
TSC vs control shift room	NO similarity of performers is present between tasks	ZD
Different team	A low level of performer similarity exist	LD
Different individuals with same qualification	The level of performer similarity is medium	MD
Same team	High level of performer similarity is present between tasks	HD
Same person	The tasks are accomplished by the same individual	CD

Table 4: Judgement on factors given by experts after transformation

Step 4. Convert qualitative judgement into representation of D numbers: In the previous work in the HRA, the lack of objectivity is always a severe problem. The highlight of this paper is the representation of the expert’s judgement, by which could effectively represent the judgement in an reasonable way as well as offer a new way to deal with Multiple criteria decision making problem (MCDM). The transformation from the judgement into the D numbers is shown in Eq. (9).

Take the "the average age among performers" of performer A as an example:

$$D_{age}^A = \{(HD, 0.6), (CD, 0.4)\}.$$

Step 5. Conclude the best performers based on D numbers: given the existed judgement, we can calculate the utility of each factor using Eqs. (8-13). Firstly aggregating the three influential factor one by one, then the utility of performer is obtained.

Take the performer A as an example:

$$D_{age}^A = \{(HD, 0.6), (CD, 0.4)\}$$

$$D_{ope}^A = \{(HD, 0.3), (CD, 0.7)\}$$

$$D_{time}^A = \{(CD, 1.0)\}$$

To simplify the representation and calculation, it translates the qualitative judgement into numerical form: the dependence level CD, HD, MD, LD, ZD are corresponding to 5, 4, 3, 2, 1 respectively. The rest of the paper would follow this simplification.

$$D_{age}^A = \{(4, 0.6), (5, 0.4)\}$$

$$D_{ope}^A = \{(4, 0.3), (5, 0.7)\}$$

$$D_{time}^A = \{(5, 1.0)\}$$

According to Eqs. (9-12), the integrated D numbers by fusing above three D numbers is obtained:

$$D_{performerA} = D_{age}^A \oplus D_{ope}^A \oplus D_{time}^A$$

$$D_{performerA} = \{(4.5, \frac{4.9}{16}), (4.75, \frac{6}{16}), (5, \frac{5.1}{16})\}$$

Then using Eq. (14), it can conclude:

$$I(D_{performerA}) = 5 \times \frac{5.1}{16} + 4.75 \times \frac{6}{16} + 4.5 \times \frac{4.9}{16} = 4.7531$$

In the transformation from expert’s judgements into D numbers, the more dependent the influential factors of SP are, the higher value the D numbers would be. Therefore, it is could be said that by comparing the I(D) of each factor, the smaller number of I(D) is, the better performer is. Then the best performer is obtained.

In this paper, a transformation form D number to BPA is defined. Assuming there are several D numbers of one individual, the translation from D numbers into BPA is defined as:

$$D_i^1 = \{(b_1, v_1), (b_2, v_2)\}$$

$$D_j^1 = \{(b_1, v_3), (b_2, v_4)\}$$

$$D_k^1 = \{(b_1, v_5), (b_2, v_6)\}$$
(15)

the BPA is obtained:

$$m(b_1) = \frac{v_1 + v_3 + v_5}{n}, m(b_2) = \frac{v_2 + v_4 + v_6}{n} \quad (16)$$

where n is the number of D numbers.

Step 6. verify the gained result by calculating CHEP: taking advantage of above process, the rank of alternative performers is obtained. In this paper, using Eqs. (15-16), the BPA of performers is obtained. Combining with the other two factors, "closeness in time" and "task relatedness", which are constant in order to control variables, to calculate the CHEP using Eqs. (1-7).

Take the above numerical data of performer A as an example. according to the Eqs. (15-16), the BPA of performer A is obtained:

$$m_{performer}(5) = 0.7, m_{performer}(4) = 0.3$$

Then assume

$$m_{time}(5) = 0.2, m_{time}(5) = 0.6, m_{time}(5) = 0.2$$

$$m_{task}(5) = 0.2, m_{task}(4) = 0.5, m_{task}(3) = 0.3$$

Thus according to the Eq. (5), the combination result $m_{performer} \oplus m_{time} \oplus m_{task}$ is:

$$m_{performerA}(5) = m_{performer}(5) \oplus m_{time}(5) \oplus m_{task}(5) = 0.2373$$

$$m_{performerA}(4) = m_{performer}(4) \oplus m_{time}(4) \oplus m_{task}(4) = 0.7626$$

According to the Eq. (7), we can conclude $Betp(XD)=m(XD)$, because the used data is single subset.

where $XD=CD,HD,MD,LD,$ and ZD .

Finally, the conditional human error probability (CHEP) $P(B|A)$ is calculated using Eq. (1) as:

$$P(B|A) = \sum_{XD} BetP(XD) \times P_{XD}(B|A) = 0.2373 \times \frac{1+0.01 \times 0}{1+0} + 0.7626 \times \frac{1+0.01 \times 1}{1+1} = 0.6224$$

Assume that the failed probability of task B is 0.01. Given the previous failed task A, the reason why the failed probability of later task B is very high up to 0.6224 is that the relationship between the two successive tasks is complete dependent or highly dependent.

4 Application

In this section, a working model for post initiator HFEs of a nuclear power plant is used to illustrate the whole procedure of the proposed method. Furthermore, the working model of D numbers is used to determine the best performers that is a kind of multiple criteria decision making (MCDM). Then the traditional method in HRA is used to verify the proposed working model. At the end of this section, the effect of D numbers and its relationship with HRA will be discussed.

4.1 Selection of best performers

The identified input factors of interest and their relationship in the working model are shown in Fig. 3. According to the THERP method, three influential factors ("the average age difference", "the average trainees time difference" and "the average operation time in solving the same problem") directly affect the performers, which is the one of influential factor to dependence level. These factors are not necessarily relevant, but the model has enough complexity to illustrate the application of the methodology.

For each influential factor, anchor points and linguistic judgements corresponding to factor are provided by experts, as shown in Tables (1-4). In this paper, in order to figure out the best performer, D numbers is used as the representation of judgement offered by experts.

The representation of judgement in D numbers mainly depends on the number of experts who are in favor of specified judgment. Take the data in Table 5 as an example, as it clearly

shows, there are five experts giving judgement. And MD of one expert, CD of two experts, HD of two experts. Thus according to the percentage, it can obtain:

$$D(\text{factor})=(\text{HD},0.4)(\text{CD},0.4)(\text{MD},0.2)$$

Expert	Expert1	Expert2	Expert3	Expert4	Expert5
Level of factor	HD	HD	CD	CD	MD

Table 5: The example of judgement on factor

According to the above discussion, the representation of judgement in D numbers is shown in Table 6.

AlternativeD numbersFactor	Age	Operation	Time
Performer 1	(5,0.4)(4,0.6)	(5,0.7)(4,0.3)	(5,1.0)
Performer 2	(5,0.1)(4,0.6)(3,0.3)	(4,0.7)(3,0.3)	(5,0.1)(4,0.9)
Performer 3	(4,0.3)(3,0.7)	(3,0.6)(2,0.4)	(4,0.3)(3,0.4)(2,0.3)
Performer 4	(3,0.6)(2,0.4)	(3,0.1)(2,0.9)	(2,0.4)(1,0.6)

Table 6: The representation of influential factors in D numbers

The performers are determined by three factors (age, operation, time) jointly, thus this step is to aggregate the D numbers of the influential factors. Using Eqs. (8-13) , the result is shown in the Table 7:

Performer	D numbers
Performer A	$(4.5, \frac{4.9}{16})(4.75, \frac{6}{16})(5, \frac{5.1}{16})$
Performer B	$(3.5, \frac{5.1}{30})(3.75, \frac{6.4}{30})(4, \frac{7.3}{30})(4.25, \frac{7.7}{30})(4.5, \frac{2.2}{30})(4.75, \frac{1.3}{30})$
Performer C	$(2.25, \frac{2.3}{24})(2.5, \frac{3.2}{24})(2.75, \frac{4.8}{24})(3, \frac{3.6}{24})(3.25, \frac{4.8}{24})(3.5, \frac{3.2}{24})(3.75, \frac{2.1}{24})$
Performer D	$(1.5, \frac{3.7}{20})(1.75, \frac{4.4}{20})(2, \frac{6}{20})(2.25, \frac{3.6}{20})(2.5, \frac{2.3}{20})$

Table 7: The integration of D numbers: $D_{age} \oplus D_{operation} \oplus D_{time}$

In order to select the optimal performer, given the existed judgement, the I(D) like a kind of utility needed to be calculated as a evaluate criteria by using Eq. (14).

$$\begin{aligned}
 I(D_{performerA}) &= 4.5 \times \frac{4.9}{16} + 4.75 \times \frac{6}{16} + 5 \times \frac{5.1}{16} = 4.735 \\
 I(D_{performerB}) &= 3.5 \times \frac{5.1}{30} + 3.75 \times \frac{6.4}{30} + 4 \times \frac{7.3}{30} + 4.25 \times \frac{7.7}{30} + 4.5 \times \frac{2.2}{30} + 4.75 \times \frac{1.3}{30} = 3.995 \\
 I(D_{performerC}) &= 2.25 \times \frac{2.3}{24} + 2.5 \times \frac{3.2}{24} + 2.75 \times \frac{4.8}{24} + 3 \times \frac{3.6}{24} + 3.25 \times \frac{4.8}{24} + 3.5 \times \frac{3.2}{24} + 3.75 \times \frac{2.1}{24} = 2.869 \\
 I(D_{performerD}) &= 1.5 \times \frac{3.7}{20} + 1.75 \times \frac{4.4}{20} + 2 \times \frac{6}{20} + 2.25 \times \frac{3.6}{20} + 2.5 \times \frac{2.3}{20} = 1.955
 \end{aligned}$$

As shown in Fig. 4, performer A has biggest I(D), which means the worst performer. The assumption in this paper is that the best performer should be with the lowest CHEP. The relationship between I(D) and conditional human error probability (CHEP) is positive correlation, thus we conclude the performer D should have the lowest CHEP. In the next section, the verification will be discussed.

4.2 Verification

In the above section,the best performer has been selected. But for verifying our assumption, the final CHEP is necessary. By comparing the conditional human error probability (CHEP), the performer with the lowest CHEP means that performer has lowest probability to make mistakes.

In reality, the alternative performers will face same problem, under the same environment, at the same time, for which we assume the factors of "closeness in time" and "task relatedness" are same for each case. And the BPA of "similarity of performer" is obtained by Eqs. (15-16) and is illustrated in Table 8.

	Performers	Task	Time
A	$m(5)=0.7;m(4)=0.3$	$m(5)=0.2;m(4)=0.6;m(3)=0.2$	$m(5)=0.2;m(4)=0.5;m(3)=0.3$
B	$m(5) = \frac{0.2}{3}; m(4) = \frac{2.2}{3}; m(3) = \frac{0.6}{3}$	$m(5)=0.2;m(4)=0.6;m(3)=0.2$	$m(5)=0.2;m(4)=0.5;m(3)=0.3$
C	$m(4) = \frac{0.6}{3}; m(3) = \frac{1.7}{3}; m(2) = \frac{0.7}{3}$	$m(5)=0.2;m(4)=0.6;m(3)=0.2$	$m(5)=0.2;m(4)=0.5;m(3)=0.3$
D	$m(3) = \frac{0.7}{3}; m(2) = \frac{1.7}{3}; m(1) = \frac{0.6}{3}$	$m(5)=0.2;m(4)=0.6;m(3)=0.2$	$m(5)=0.2;m(4)=0.5;m(3)=0.3$

Table 8: The BPA of different cases

In this paper, it assumes that the weight of factors of same level is same. By using D-S evidence theory Eq. (6), the fused BPA of each factor is obtained as shown in Table 9.

Case	A	B	C	D
BBA	$m(5)=0.2373$ $m(4)=0.7627$	$m(5)=0.0114$ $m(4)=0.9375$ $m(3)=0.0511$	$m(4)=0.6383$ $m(3)=0.3617$	$m(3)=1$

Table 9: The final result of BPA

Due to the data used in the paper are all single subset as well as $m(\emptyset) = 0$, according to the Eq. (7), the numerical value of BetP is equal to the numerical value of BPA. Assume that basic human error probability of the subsequent task T_b is $P(B)=0.01$. Then the conditional human error probability (CHEP) is calculated using Eq. (1), the result is shown in Table 10 and Fig. 4(b).

Case	A	B	C	D
CHEP	0.6224	0.5387	0.4337	0.2286

Table 10: The final result of CHEP

4.3 Discussion

The result of proposed method consists of two parts: the selection of alternatives and the calculation of CHEP. In the first part, the D numbers is used to represent the judgements given by experts. It is reasonable and intelligible way to handle such problem. The number of I(D) is treated as a criteria for performers. The smaller I(D) is, the better performer is. And the second part discusses the conditional human error probability (CHEP) that means that the failure probability of the following task given the failed preceding task. It is obvious the lower CHEP indicates the better situations. By comparing with Fig. 4, it concludes the relationship between I(D) and CHEP is positive correlation. Thus the gained result complies with our assumption, the performer A selected through proposed method has the highest CHEP 0.6224. It means that the task tends to fail with the most high probability when performer A is selected.

$$I(D_{performerA}) > I(D_{performerB}) > I(D_{performerC}) > I(D_{performerD}) \text{ CHEP} : A > B > C > D.$$

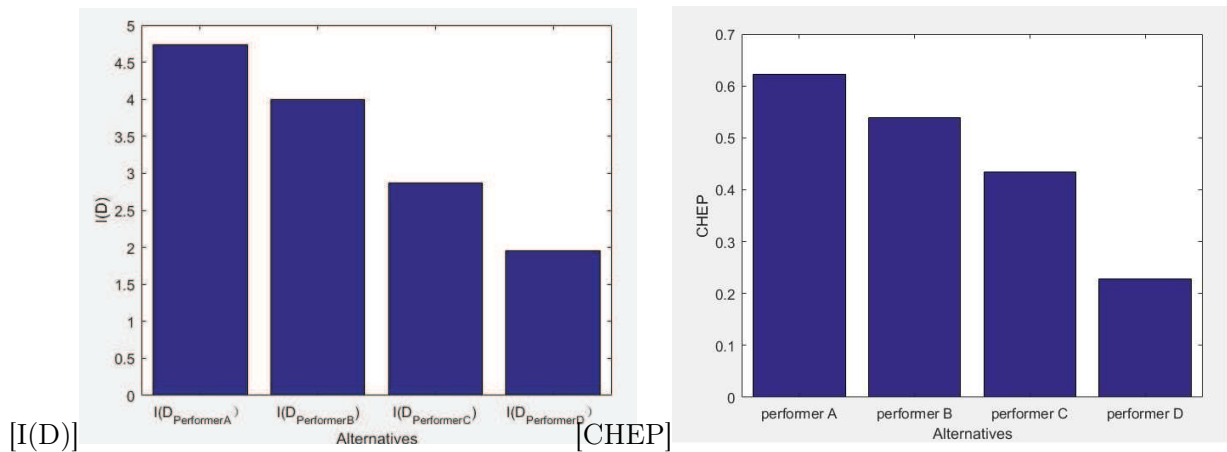


Figure 4: The comparison of ID and CHEP

5 Conclusion

In previous works in human reliability analysis (HRA), the influence of performer is not paid enough attention. In this paper, the evaluation method based on D numbers is presented to deal with the selection of alternative performers in an reasonable and simple way. In the real world, there is no doubt that performers are the main factor that affect our selection. The contribution of this paper is that offering a new way to translate the BPA into D numbers, which is more flexible than traditional ways and reduce the subjectivity at some extent. The final result demonstrates the effectiveness of the proposed method. In the future works, we would take the weights of different influential factors into consideration to make the predicted result more accurate.

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Conflict of interest

The authors declare that there is no conflict of interests regarding the publication of this paper.

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